Digital Computer Laboratory
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SUBJECT: "L" CATHODES IN ELECTRON GUNS

To: The Storage Tube Group

From: T. Spencer Greenwood

Date: April 21, 1953

Abstract: This memorandum is the text of a report presented at the Thirteenth Annual M. I. T. Physical Electronics Conference on March 26, 1953. It summarizes the results of the work undertaken to determine the applicability of "L" cathodes to storage tubes during the period of August 1952 to March 1953. These results indicate that the emission capabilities of the "L" cathode are such that they can be used in place of the oxide cathode in the storage tube high-velocity gun. The useful life of the cathodes and the limitations imposed by grid emission are still under investigation since they are long term problems and subject to some statistical variation.

The present paper is a brief summary of the initial experience of the M. I. T. Digital Computer Laboratory in applying "L" cathodes to electron guns. The ultimate objective of this work is to include such a gun in the electrostatic storage tube which is used as the high-speed storage element of the Whirlwind I computer. At the present time these tubes are using guns with oxide-coated cathodes. While operationally, these are quite satisfactory, their life, particularly in the reading-writing gun, is often the limiting factor in tube life. There is a second gun in the tube which is "on" a very large percentage of the time and produces a large number of positive ions. These ions bombard the cathode of the reading-writing gun and eventually reduce its emission to an inoperative level. At the present time few tubes remain in service after 5000 hours of life.

The "L" cathode, because of its structure, is more immune to positive ion bombardment and for this reason is being considered as a possible replacement for the oxide cathode.

The present report covers the initial work undertaken to determine whether the "L" cathode gun could reproduce the characteristics of the present gun. Briefly, it was required that the "L" cathode be used in an RCA type 5U gun operating at 2500 volts accelerating potential and be capable of delivering a current of 30 to 40 μa into a focused spot of .025" to .030" diameter. It was desired that the grid drive be within a factor of 2 of the present drive. Obviously for any advantage to accrue from the use of "L" cathodes, the emission should be stable for no less than 5000 hours and preferably 10,000 or more hours.

Physically, the planar "L" cathode is almost identical to the regular oxide cathode. The earliest type, called the cavity type, is shown in Figure 1. It was with this type that most of the experimental work was done. More recently the impregnated type has been used. This differs from the cavity type in that it has no internal separator, no ridge, and is about 10% greater in diameter. In either type the emission is produced by a monatomic layer of barium on the tungsten cap. The formation of this layer is carried out in the cavity type by thermal breakdown of the carbonate to barium oxide, subsequent reduction of the oxide by the tungsten, and diffusion of barium to the emitting surface. In the impregnated type, the tungsten cap is already infused with barium oxide and, theoretically, only the reduction and diffusion steps are necessary for activation. Because of the instability of BaO, it would appear necessary to avoid excessive contact between the impregnated type cathode, and CO_2 and water vapor, during the handling and construction stage. However, prolonged exposure does not seem to seriously impair emission.

The first major problem involved in using the "L" cathodes arises during the construction of the gun. While the "L" cathode is physically similar to the oxide cathode, the temperatures at which it is necessary to process the "L" cathode make the standard cathode mounting unsuitable. The standard mount uses a ceramic support in direct contact with the cathode, but with the "L" cathode such direct contact is reportedly apt to result in cathode poisoning.

However, in order to achieve the proper grid - cathode spacing of 0.005" in the 5U gun, it is necessary to have a mount which is rigid both mechanically and thermally and one which conducts as little heat as possible away from the cathode. A single wire mount is unsatisfactory and the mount that was finally used is shown in Figure 2. The 5U gun has two ceramic rods supporting the first two grids and the tantalum crosspiece shown was mounted on these two rods just below the first grid. A satisfactory weld between the grid and cathode was made by using platinum as a flux. The mount was generally very satisfactory; its largest drawback was the difficulty encountered in accurately adjusting the grid to cathode spacing. A later, more refined design is shown in Figure 3. This design provides an assembly which fits inside the first grid and which is supported in the same manner as the conventional cathode. Heat conduction in this mount is held to a minimum by supporting the cathode at only four welded points. Both mount designs were based on the supposition that cathode temperatures would be too high for direct contact ceramic mounts. Recently, however, the possibility of activating at lower temperatures has arisen and if this proves satisfactory, a reevaluation of the use of ceramics is necessary.

The only other constructional problem that has occurred is in connection with the heaters of the cavity type cathode. The heaters that have been used are those supplied with the cathodes. The earliest ones were made of tungsten coated with aluminum oxide in a double wound helix form. See Figure 4C. Unfortunately, these heaters were very poorly coated; the oxide was porous and loose and resulted in frequent heater burnouts. To eliminate this problem, the manufacturer changed his technique and began supplying the cathodes with heaters installed and the entire heater cavity filled with aluminum oxide. In addition, the form of the heater was changed to a folded one as in Figure 4B. This design proved successful and no further burnouts were encountered. However, it was found that the cathode temperature was no longer a predictable function of heater voltage, current or power; hence, direct temperature observations were necessary on each tube.

The impregnated cathode heaters have not suffered these drawbacks. They are separate heaters with a hard adherent oxide coating. No burnout problem has arisen and temperature is a reasonably consistent function of heater voltage. Recent conversations with the manufacturers indicate that similar heaters will soon be available for the cavity type.

The constructional problem which existed in connection with the heaters resulted from the manufacturer's practice of supplying the heaters without extension leads. The ends of the heaters are tightly coiled and protrude about an 1/8" from the cathode. A simple and effective method of obtaining extension leads is to pull the end of the heater coil while holding the coil near the cathode. See Figure 4B. Breakage resulting from this step is negligible and none of the leads has ever failed in operation. In an apparent attempt to provide extension leads, the last lot of cathodes received were supplied with extension leads inserted in the heater coils. See Figure 4A. Of the five or six heaters used, every one either burned out or developed internal shorts. For this reason, their use has been discontinued.

The processing of the cathodes is for the most part straightforward but certain difficulties do exist. Conversion of the carbonates in the cavity is not difficult if a reasonable amount of time is allowed. It has been found to be an easily repeatable step and not excessively critical. Figure 5 shows a typical pressure curve during conversion. The actual conversion takes place at the upper peak. The lower peak is a subsidiary reaction which has not appeared to cause trouble. To some extent this extra reaction can be depressed by using more rapid temperature rises but no significant advantage accrues. The schedule used for this and other conversions was to raise the temperature in small steps in order to reach a cathode temperature of 1100°C brightness within 20 to 40 minutes. The sharp pressure drop, indicating the end of conversion, always occurs within one hour. Peak pressures are of the order of 5×10^{-4} mm of Hg.

While conversions as such are presumably not necessary on the impregnated type cathode, the initial degassing has been carried out on the same schedule used for conversion of the cavity type. A repeatable pressure variation has been obtained which bears similarities to the conversion pressures of the cavity type. In particular, a low temperature peak is obtained which is almost identical to that in Figure 5, while beyond this point the pressures corresponding to conversion in the cavity type are about two decades lower in the impregnated type but still show the double peak. It would appear that some carbonate is thus present, possibly from exposure to air during construction.

Activation differs considerably depending on which of the two types of cathodes is used. The cavity type will be discussed first. The temperature used for activation was generally 1250°C brightness; lately, however, activations have been carried out at temperatures of 1150°C_b to 1200°C_b. Apparently, satisfactory results were achieved at these lower temperatures and the behavior of the cathodes was similar to that at the higher temperature.

This behavior for four tubes is shown in Figure 6. In these curves the first grid was used as an anode and time is measured from the instant activation temperature was reached. The first three tubes were largely activated without drawing emission current except for momentary measurements. From points A-A onward, however, emission current was drawn continually. In the case of the last tube, current was drawn continually throughout activation. Generally speaking, little difference exists between activation using heat alone and activation with emission current being taken. In a practical sense, however, cathode contaminants released from the grid due to electron bombardment must be considered. Their effect is to decrease the rate of rise of emission and this can be seen in the figure on tubes RT335 and RT355. This type of poisoning varies from tube to tube and, unlike a similar effect in oxide cathode tubes, there is no particular voltage at which poisoning starts. Rather the amount of poisoning increases slowly as the voltage is raised.

Because of this poisoning, it has been found that slightly faster activations are obtained by not drawing current; however, since poisoning does occur later in tube operation it seems wise to draw current for the purpose of grid degassing. On most tubes this was done after the cathode had been at least partially activated. R-F bombardment of the grid was also used in some cases but neither method was completely satisfactory in eliminating cathode poisoning during operation.

The time required to activate the cavity type cathode is widely variable. It will be noted in Figure 6 that activation consists first of a period in which little or no activation takes place followed by a very rapid current rise. The variability in the no-activation period indicates a wide variation in the diffusion time of the barium. Figure 6 is by no means indicative of the variation in this delay. A delay of up to 6 hours has been observed. However, it is encouraging to note that no cathode has failed to activate if given sufficient time. Patience has been a necessary processing tool. The activation of the impregnated type cathode is a different story. As soon as these cathodes reach activation temperature (1200 - 1250°C has been used, but a lower one may be possible), the cathode is generally quite active. If not fully active a relatively short period will complete activation. The absence of any activation delay goes hand-in-hand with the fact that barium sources are already dispersed in the tungsten and barium is not required to diffuse any appreciable distance. On the other hand, the availability of barium from points distant from the cathode surface dictates at least a short aging to attain stability. Poisoning from grid contaminants appears to be much less in this type cathode. This fact, together with the shorter activations, makes this cathode attractive for processing simplicity.

Beyond the foregoing, no further processing is essential. Actually an aging period was always included but this proved to have more value in degassing the gun apertures than in stabilizing the cathode.

The test results of the "L" cathode guns have been moderately satisfactory to date. To meet the emission requirements of 30 - 40 μa, it has been found necessary to operate the cathodes at a temperature of about 950°C_b. At this temperature about 60 μa are available but Faraday-cage measurements have shown that temperature saturation adversely affects the beam shape above 40 μa. This operating temperature seems to be suitable for either type of cathode although the impregnated type shows a much greater variation in emission with temperature than does the cavity type. This may be due to changes in the state of activation of the impregnated type with temperature

The emission level obtained at 950°C is only about one half that of the oxide cathode gun and it is thus highly important that this emission be stable. Unfortunately, this is not always the case. As has been pointed out the cavity type, particularly, is subject to poisoning. Besides that poisoning caused by grid contaminants, poisoning of the center of the cathode only has occurred. While none of the poisons are permanently destructive and the cathodes may be reactivated, the situation is undesirable. However, there is considerable variation in the extent of poisoning from tube to tube and if suitable degassing procedures are carried out in processing, and operating temperature is held in the 950°C range, the poisoning causes little trouble. As was previously stated, the impregnated type suffers less from poisoning but evidence of its existence is present.

At present, the life of the cathodes has not been fully evaluated. While this was intended to be one of the first characteristics to be investigated, heater burnouts and poisoning clouded the results on early tubes. Despite this, two of the more satisfactory tubes were run at 900°C for 9000 hours without failure. On other tubes it appeared that operation at 1050°C was possible for at least 2500 hours. While these results were fragmentary, they were encouraging enough to expect 8,000 to 10,000 hour life at operating temperatures of 950°C.

No discussion of "L" cathodes is complete without some consideration of grid emission. The relatively high rate of barium evaporation and the proximity of the grid and cathode give rise to grid emission of significant amounts. Generally, the emission does not reach an observable limit until some operation time has elapsed. In the storage tube this observable limit is reached when the contribution to beam current density of grid emission is about 6 orders of magnitude lower than the total beam current. Another increase of perhaps a factor of 100 over this is allowable before such emission is detrimental to tube operation. The time of appearance of grid emission is variable and depends to a considerable extent on processing history. Specifically, the length of time the cathode is held at activation temperature, after activation is complete, should be held to a minimum.

In a tube which had a fairly typical processing, the first appearance of grid emission came after 1500 hours of operation. It was found at this time that a relatively light r-f bombardment of the grid removed the grid emission without injury to the cathode emission. Subsequently the grid emission reappeared after 500 hours. If the level of grid emission at these times had been detrimental, it would be necessary to consider grid emission a severe drawback. Unfortunately, since life studies of grid emission have only recently been started, it is not possible to state how much time is required for the emission to reach the detrimental level and this may be much longer than that quoted for observable emission.

In connection with impregnated cathodes, it has been observed that grid emission to the cathode is greater but this difference does not seem to be reflected in a first order difference in the beam current density contribution.

The conclusions which have been reached from the investigations conducted thus far indicate that the "L" cathode will serve as a satisfactory substitute for oxide cathodes in electron guns if the current requirements are moderate. Whether the resulting gun will maintain its emission for longer periods than the oxide cathode is still an open question. In some applications grid emission will be important, and in these cases life may be severely limited. The impregnated cathode has several advantages over the cavity type in ease of processing, freedom from poisoning, and slightly greater emission. It does have the drawback of higher heater-cathode leakage and possibly greater grid emission in critical applications. Of some practical interest are the heater voltages required for 950°C operation since they are non-standard. These are about 8 volts for the cavity type and 10 for the impregnated type. Redesign of the heaters can, of course, bring these values down to 6.3 volts, but not without some danger of burnouts during processing.

Signed T. Spencer Greenwood
T. S. Greenwood

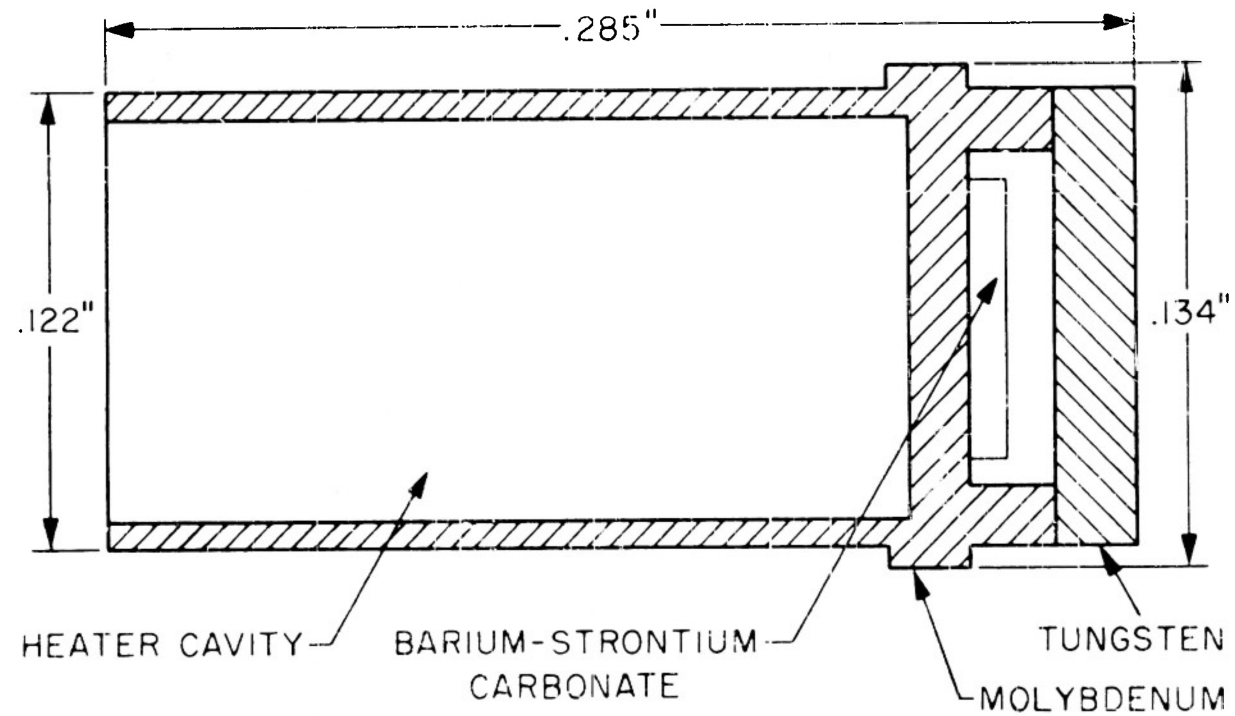
Approved C. L. Corderman
C. L. Corderman

TSG:RMC

Attached:

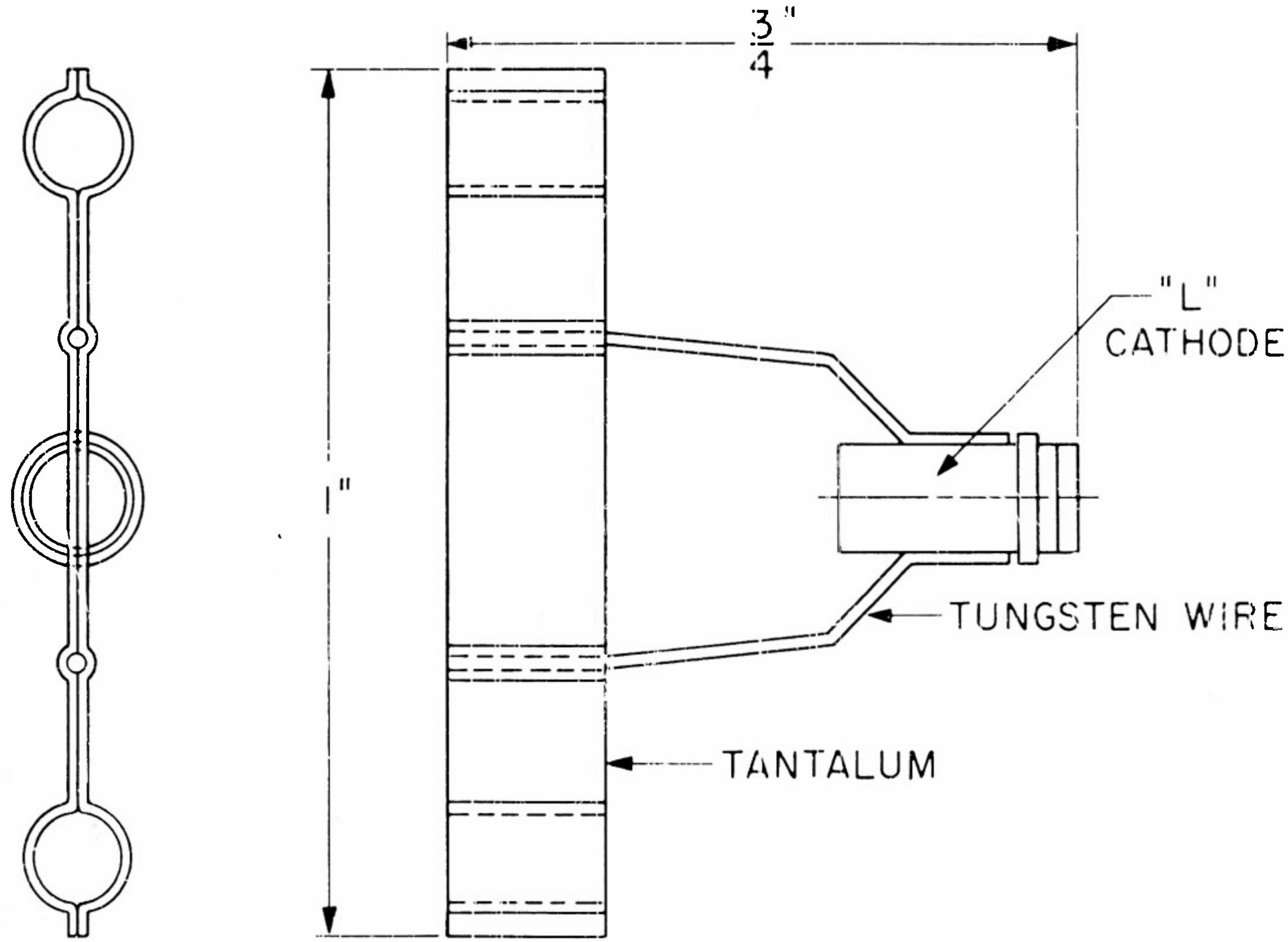
Figure 1:	A-54277
Figure 2:	A-54276
Figure 3:	A-54202
Figure 4:	A-54203
Figure 5:	B-54274
Figure 6:	B-54275

A-54277



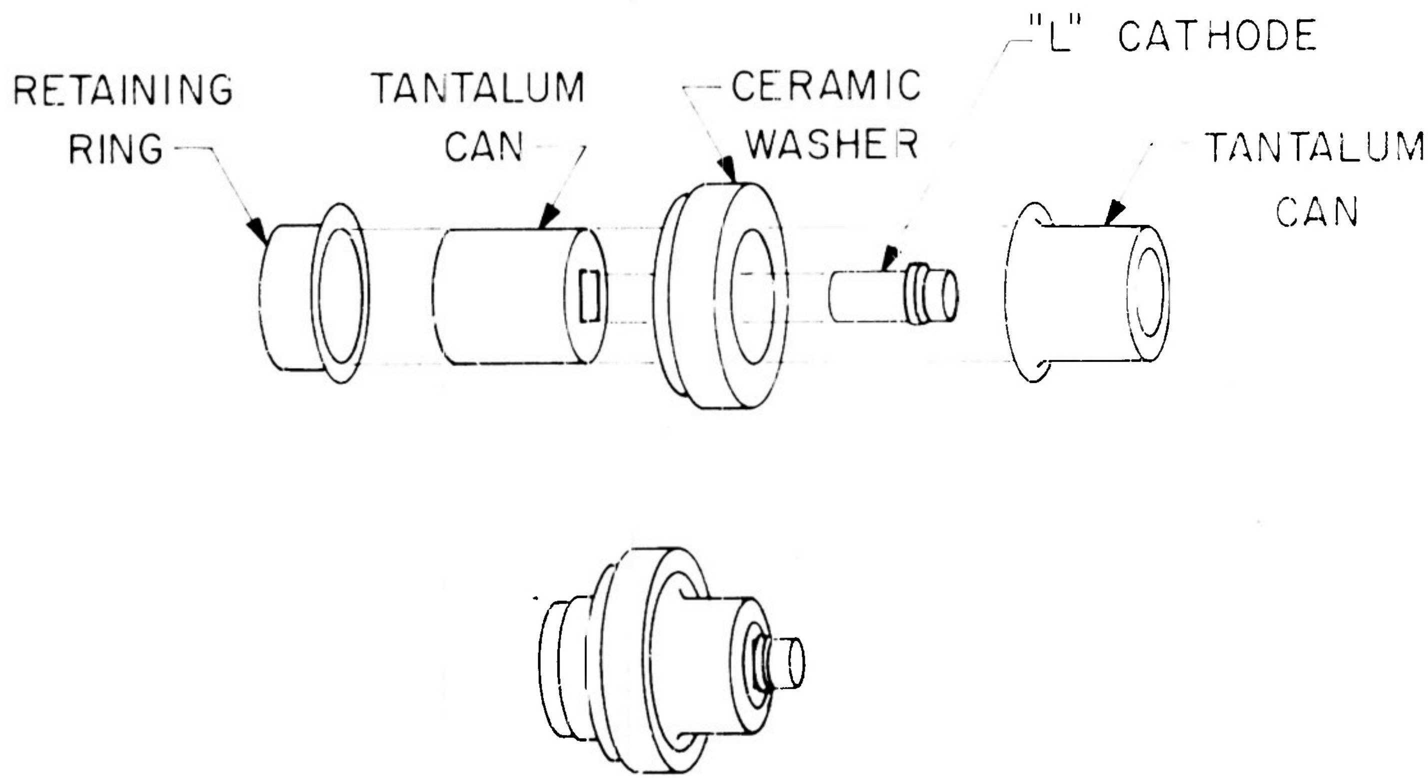
SECTIONAL VIEW OF "L" CATHODE

A-54276



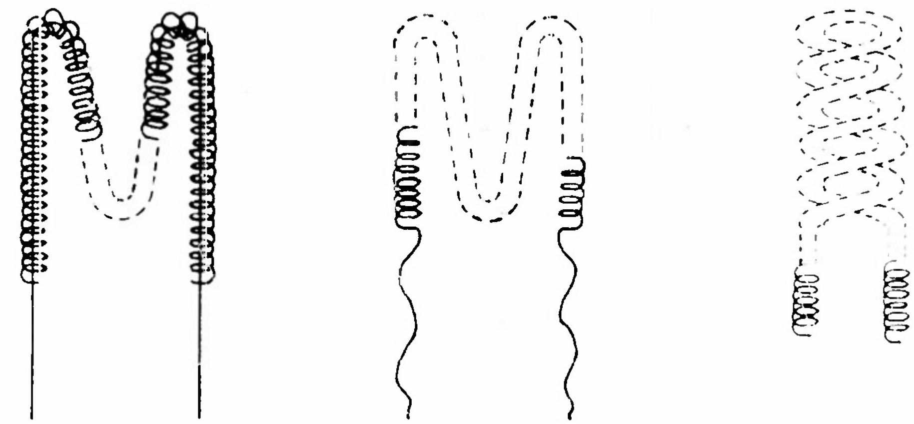
"L" CATHODE MOUNTING

A-54202



"L" CATHODE MOUNT

A-54203



(A) FOLDED HEATER WITH EXTENSION LEADS

(B) FOLDED HEATER WITHOUT EXTENSION LEADS

(C) DOUBLE WOUND REVERSE HELIX

"L" CATHODE HEATERS

B-54274

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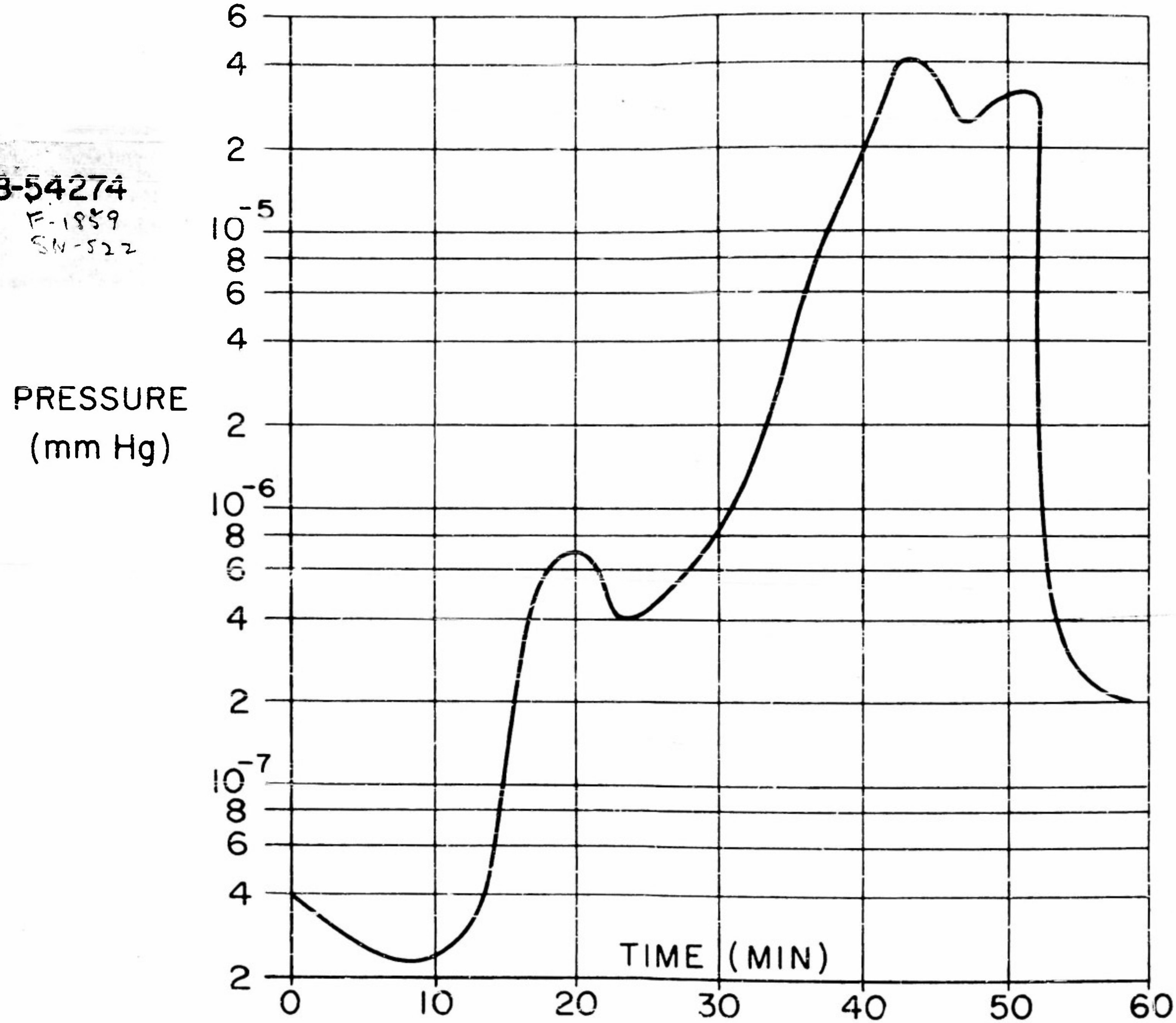
F-1859
SN-522



PRESSURE DURING CONVERSION, RT-324

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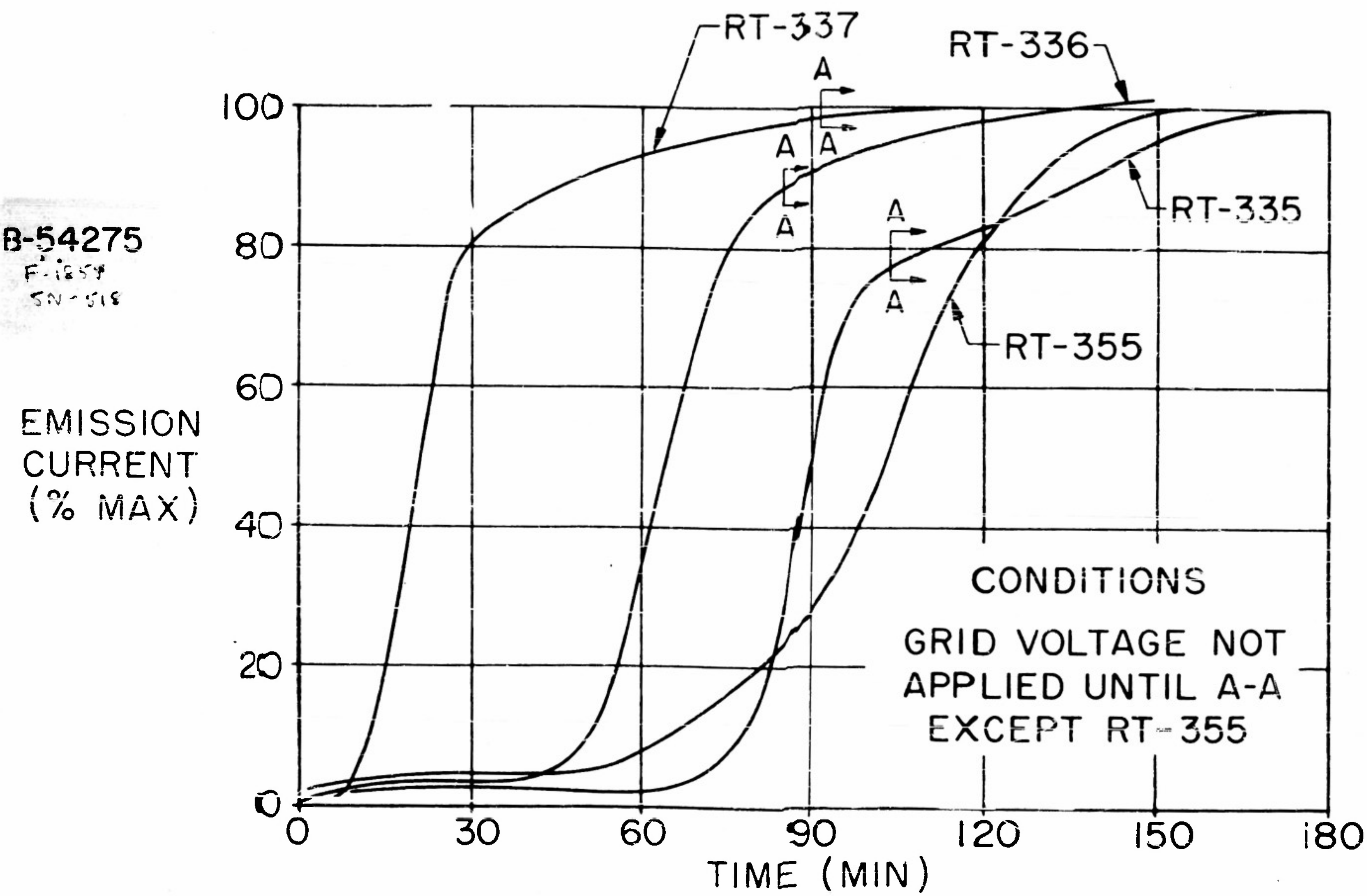
SN-518



ACTIVATION OF "L" CATHODES

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